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Electrical Engineering Research Laboratory
The University of Texas
Austin, Texas

Report No. 6-48 29 June 1962

EVALUATION OF EARTH PROBE ANTENNAS FOR VLF RECEPTION

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Contract AF ,?(604)-8513
Project 4610
Task 461001

Prepared for
Electronics Research Directorate
Air Force Cambridge Research Laboratories
Office of Aerospace Research
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ABSTRACT

This report is an evaluation of an earth probe antenna formed by connecting receiver input terminals to electrodes in the ground 343 meters apart. Reception of coherence and sferic signals on this antenna at frequencies below 50 kc/s was compared with that received on horizontal overhead antennas.

Although the voltage output from the overhead antennas was consistently higher than the signal taken from the ground probe antenna, the higher signal to noise ratio of the ground probe antenna indicated its potential use in the VLF range.

I. INTRODUCTION

The measurements described in this report were undertaken for the purpose of studying the properties of an antenna formed by grounding the ends of the lead wires from a receiver at earth probes 343 meters apart. As used, the lead wires were buried a few inches in the ground.

The signal received on this antenna was compared with that received on horizontal overhead antennas using several arrangements of the connections to the overhead wires.

Signals from several radio stations were used in the kilocycle range. At lower frequencies, it was necessary to depend on sferics to provide a source for comparison.

The antennas, as used, were electrically short. Short dipoles or monopoles become more efficient as the frequency is increased if the antenna impedance is matched to that of the receiver.[1,2,3] No attempt was made to match impedances since the results sought were primarily comparisons of the voltages present at the antenna terminal. The signals from the earth probe and overhead systems were measured by the use of identical narrow band receivers with input impedances large as compared to the antenna systems impedance.

In addition, many choices of the configuration can be made of the overhead system used as a reference. Several possible arrangements were studied and the effect of changes in height above ground were observed.

On the basis of these studies two reference arrangements were used. These were a center fed dipole and an end fed monopole whose length was one half the length of the dipole at various heights above the ground up to 8 meters for kilocycle transmitting stations. A standard height of 6 meters was chosen for the study of the natural and man-made noise.

II. EARTH PROBE ANTENNA SYSTEM

For several years this Laboratory has observed the voltage variations between electrodes spaced 343 meters due to natural earth currents both in the North-South and East-West directions.[4] The frequency range of interest in these tests was primarily below 10 cps. For the purpose of these studies, an electrode was developed made up of a cadmium rod in a solution of cadmium chloride. A slightly porous container provided excellent ground contact. The electrodes were placed approximately one meter below the surface of the ground.

For the antenna studies described in this report, the North-South path electrodes were used. RG62/U coaxial cable was buried a few inches on a line between the probes with the center conductors used as the lead-in wires from the probes to a differential preamplifier at the midpoint between the grounded terminals. The outer conductor of the coax was used as a shield and was grounded to the preamplifier. A coaxial cable was used to bring the signal from the preamplifier to the receiver in the laboratory approximately

200 meters from the preamplifier. The outer conductor of the cable was grounded at the preamplifier and at the receiver.

The signal picked up on unshielded buried wires was examined by use of No. 14 solid AWG wire paralleling the leads from the electrodes to the preamplifier. The signal to noise ratio on the unshielded buried wires was inferior to that of the shielded ones. For this reason, the shielded conductors were used in the comparison tests.

III. OVERHEAD ANTENNA SYSTEM

The overhead antenna system consisted of two co-linear, 170 meter, horizontal wires mounted on poles in such a manner that their height above ground could vary from the ground level to eight meters. These wires were parallel to and approximately 20 feet east of the earth current path. Two basic connections to these wires were used throughout the measurements, and the signal from each was compared with the earth probe antenna signals. The arrangements used were as follows:

1. A center fed dipole formed by connecting the two overhead wires to a preamplifier at the center of the path. This preamplifier was raised and lowered with the antennas. The other ends of the wires were not grounded.

2. A monopole formed by connecting the one end of one of the overhead wires to the preamplifier with the other

preamplifier terminal grounded. This arrangement might be considered as a top-loaded vertical antenna.

Various other arrangements were examined but the two listed above were selected for the comparison study.

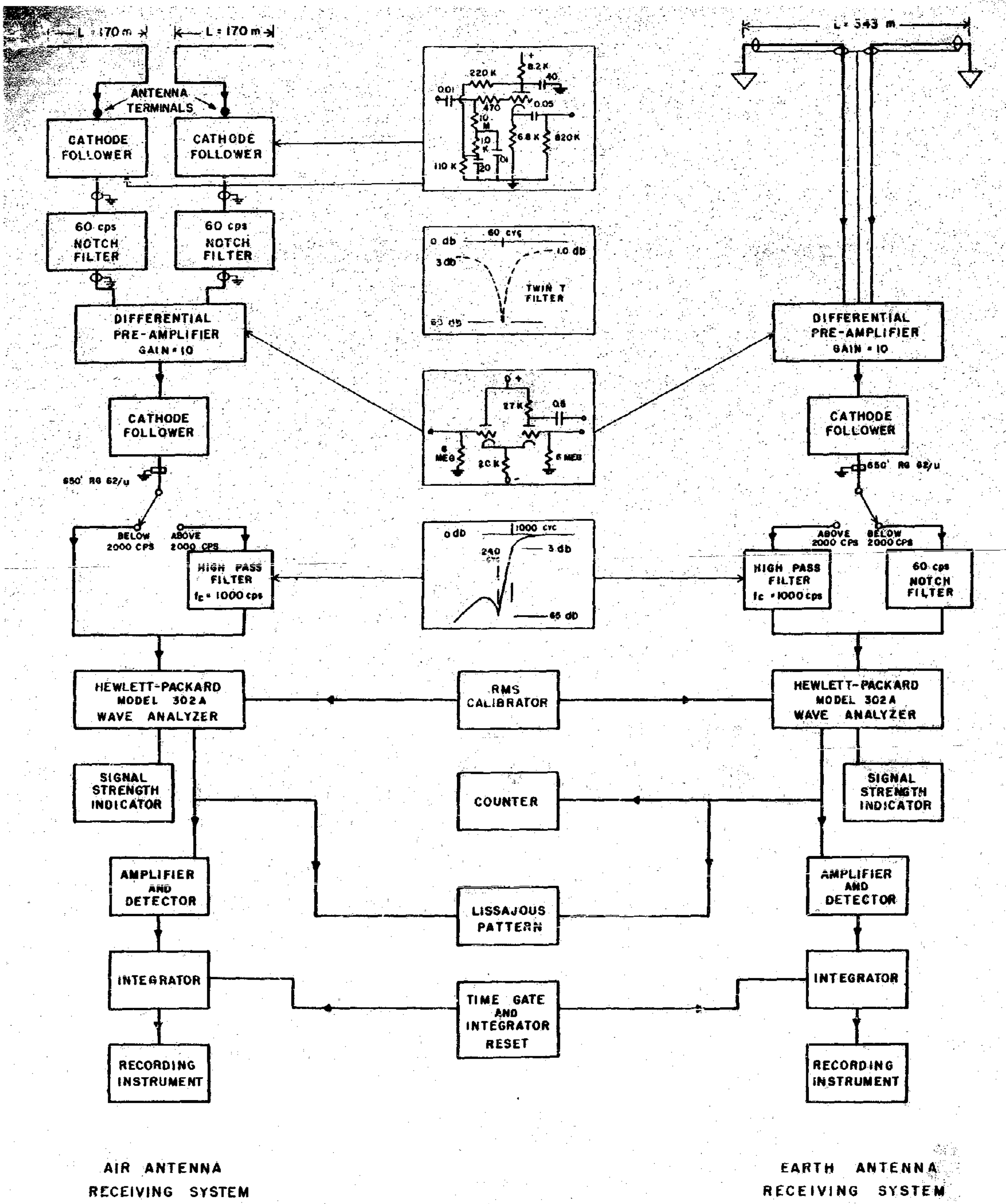
IV. INSTRUMENTATION

The receivers were essentially tuned voltmeters with very high input impedance. No attempt was made to match the system input to the antenna impedance. The radiation resistance of the antenna systems was very low (much less than 0.1 ohm) as compared to the resistance of the lead wires (approximately 0.6 ohm). The principal impedance of the overhead antennas was the self reactance which was frequency sensitive, increasing with decreasing frequency. In all cases, this impedance was much less than that of the receiver system.

The impedance of the ground probe system was essentially the dc resistance of the wires, probes, and ground path, and as such, was much smaller than that of the overhead wires.

A block diagram of the two receiving systems is shown in Figure 1. The salient features of the systems are described schematically and graphically. Although the signal flow is straightforward, there are some features that warrant a brief discussion.

Cathode followers which incorporated low frequency feedback were used in the front end of the air antenna receiving system. These preamplifiers



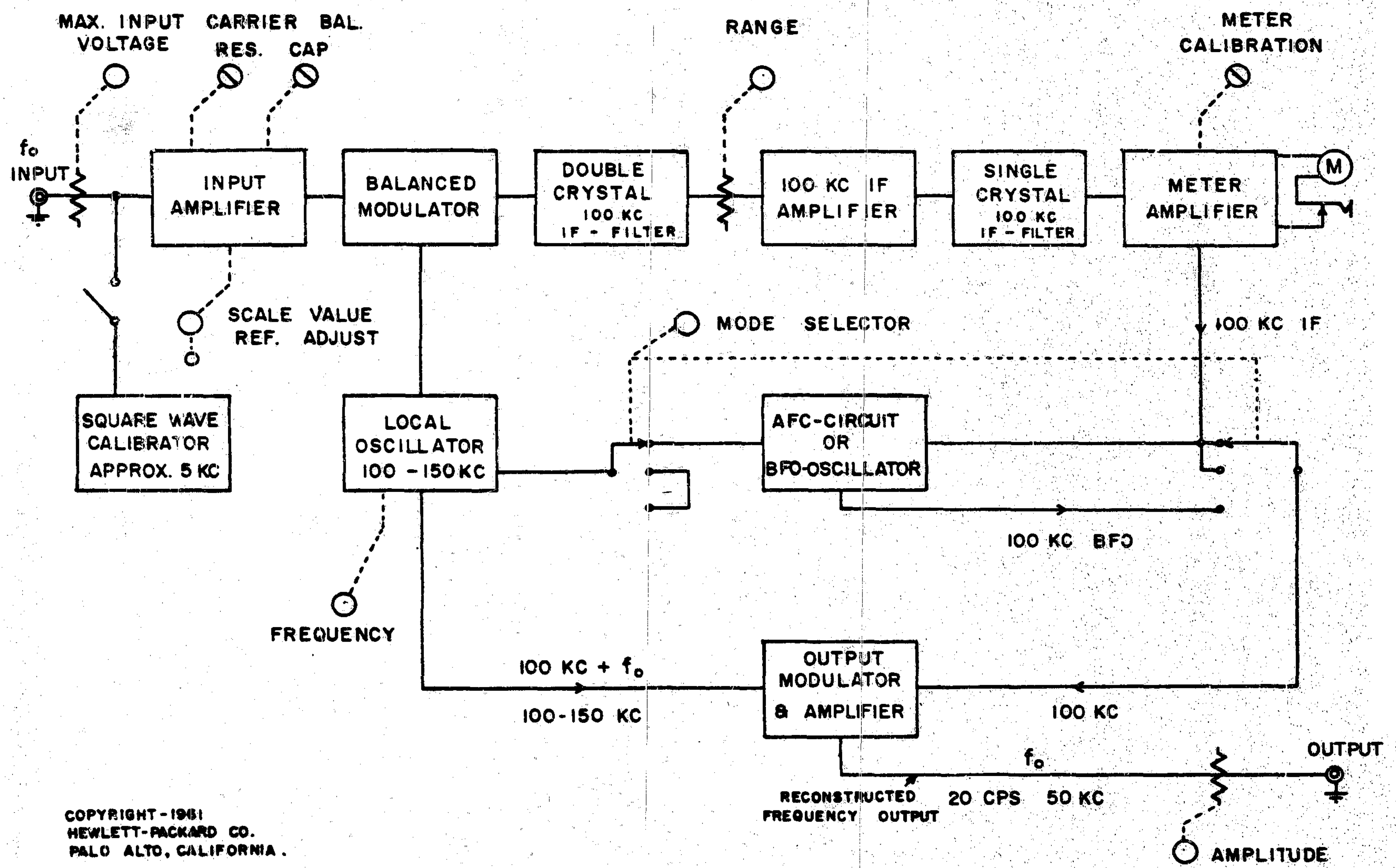
BLOCK DIAGRAM OF RECEIVING CIRCUITS

FIG. 1

were designed to have especially good noise figures when operating with large values of input impedance. The system noise for both the air and earth antenna systems was then completely negligible compared to the received signals during the entire measurement program. The twin T filters were used to reject the 60 cps pickup on the air antenna. When operating the system at frequencies above 2000 cps additional attenuation of 60 cps and its major harmonies was provided by the high pass filter. Rejection of these power line frequencies was necessary to prevent saturation of the input amplifiers in the Hewlett-Packard wave analyser. When operating the system below 2000 cps where it was not possible to use the high pass filter, the measurements of the spheric activity were restricted to those frequencies lying between the harmonics of 60 cps.

Due to the low impedance of the ground path between the probes of the earth antenna, it was not necessary to use the cathode follower pre-amplifiers in order to obtain an acceptable noise figure for the receiving system. The earth antenna was also observed to have somewhat less power line interference than the air antenna; however, some rejection of the 60 cps fundamental was required.

The block diagram of the Hewlett-Packard model 302 A wave analyser, shown in Figure 2, is self-explanatory. The two attenuators provided 140 db attenuation in 10 db steps. The dynamic range of the instrument on any selected setting of the attenuators was approximately 30 db. The narrow



BLOCK DIAGRAM HEWETT-PACKARD MODEL 302A WAVE ANALYZER

FIG. 2

bandwidth (6 cps equivalent noise bandwidth) was obtained by a single crystal filter. Those frequencies which lay within the passband were reconstructed and amplified as shown.

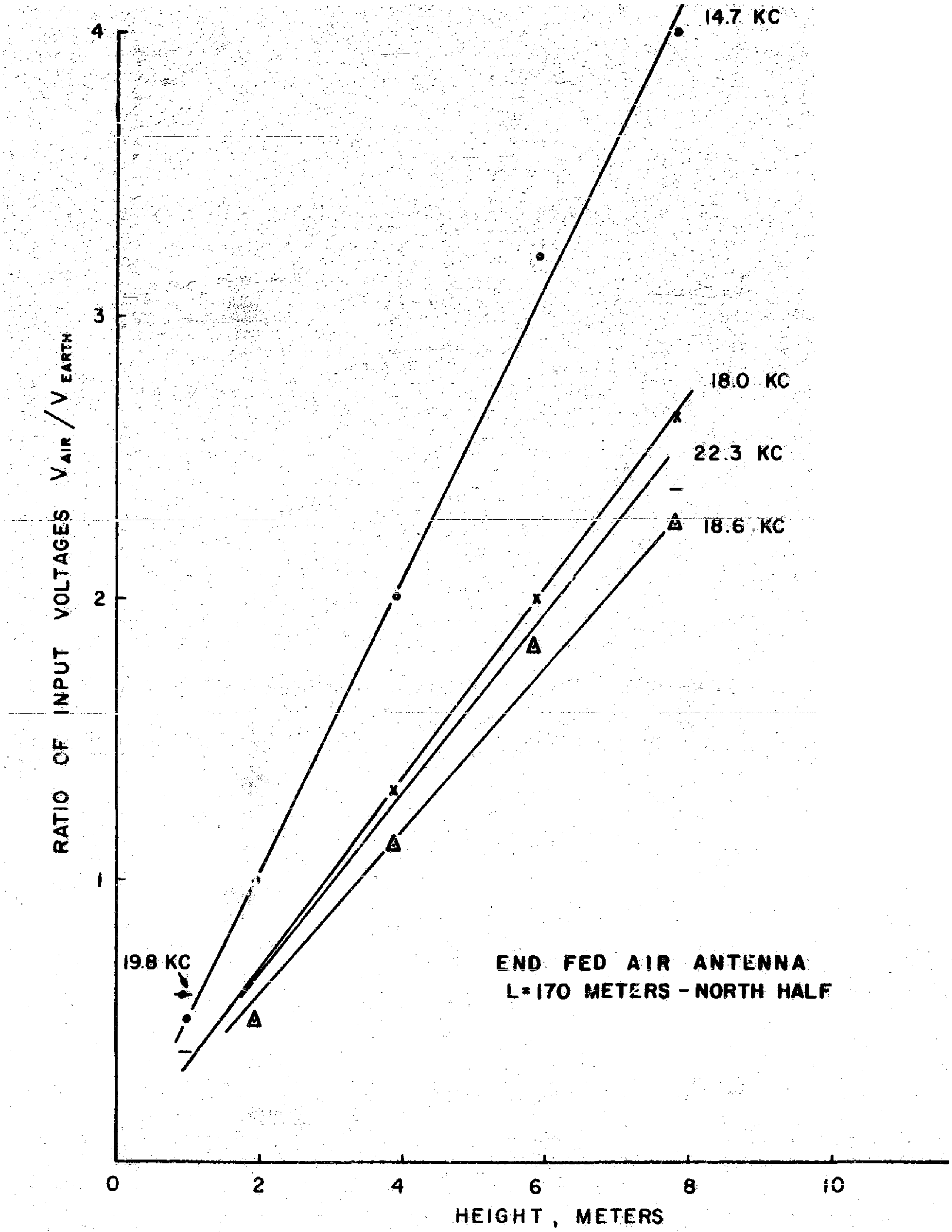
Integration intervals varied from 20 to 30 seconds for most c-w signals and from 30 to 50 seconds for sferic signals. The overall sensitivity of the receiving system for satisfactory operation of the integrator was 0.20 microvolt input. The integrator output was calibrated in RMS values by application of a single frequency voltage of known magnitude to the wave analyzer input.

V. EFFECT OF HEIGHT OF OVERHEAD ANTENNA ABOVE GROUND

A. Monopole

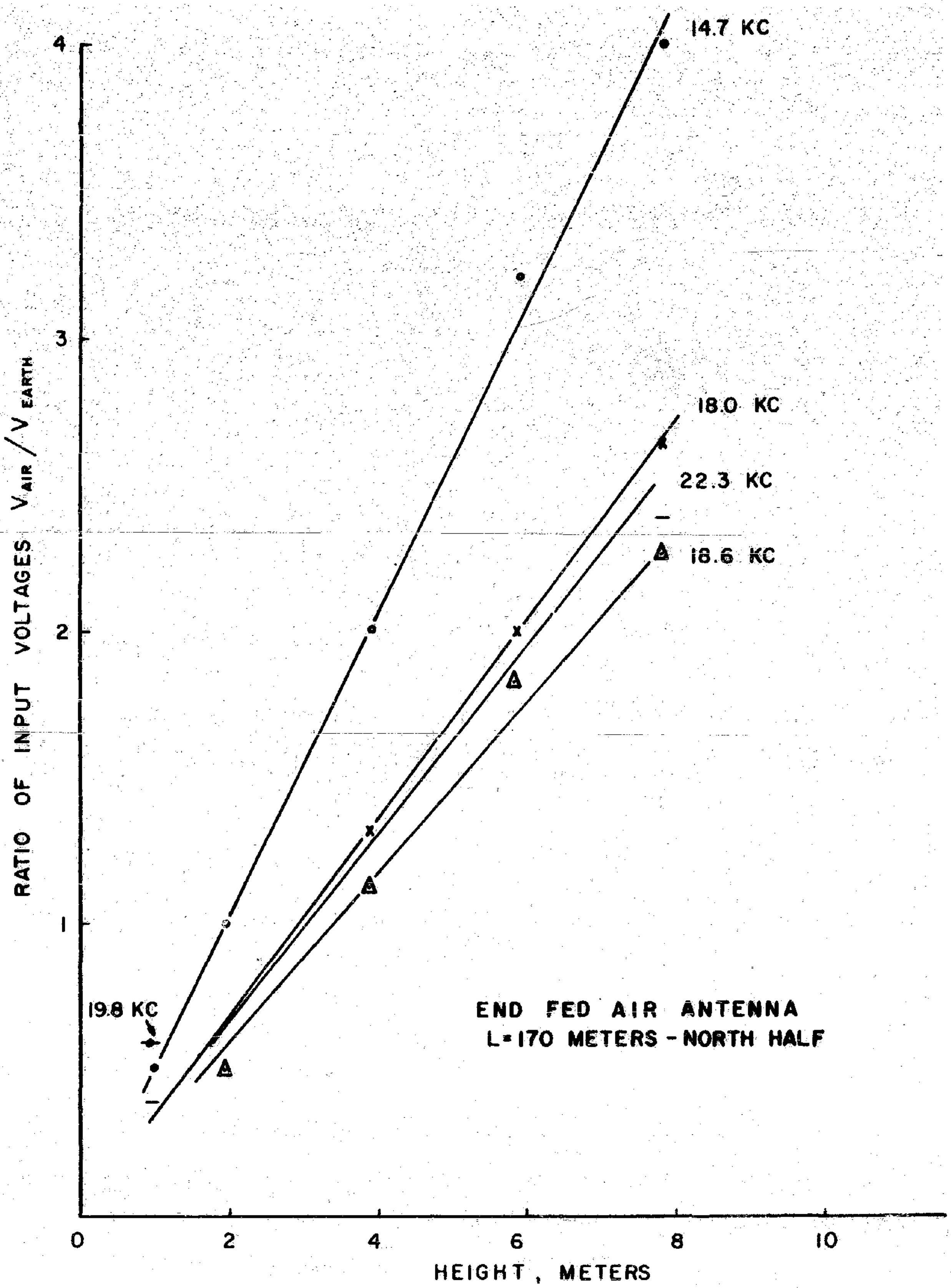
The signal received on the end-fed antenna was compared to that received on the ground probe antenna for a number of heights between ground level and eight meters for the five frequencies received from the transmitting station listed in Table 1. These data are plotted in Figure 3.

For each of the five stations, the signal voltage from the monopole increased with elevation. Their relative levels were frequency dependent as shown in later curves, but the general shape of the graphs can be approximated by straight lines passing through the origin.



RATIO AIR ANTENNA SIGNAL TO EARTH PROBE SIGNAL

FIG. 3.



RATIO AIR ANTENNA SIGNAL TO EARTH PROBE SIGNAL

FIG. 3.

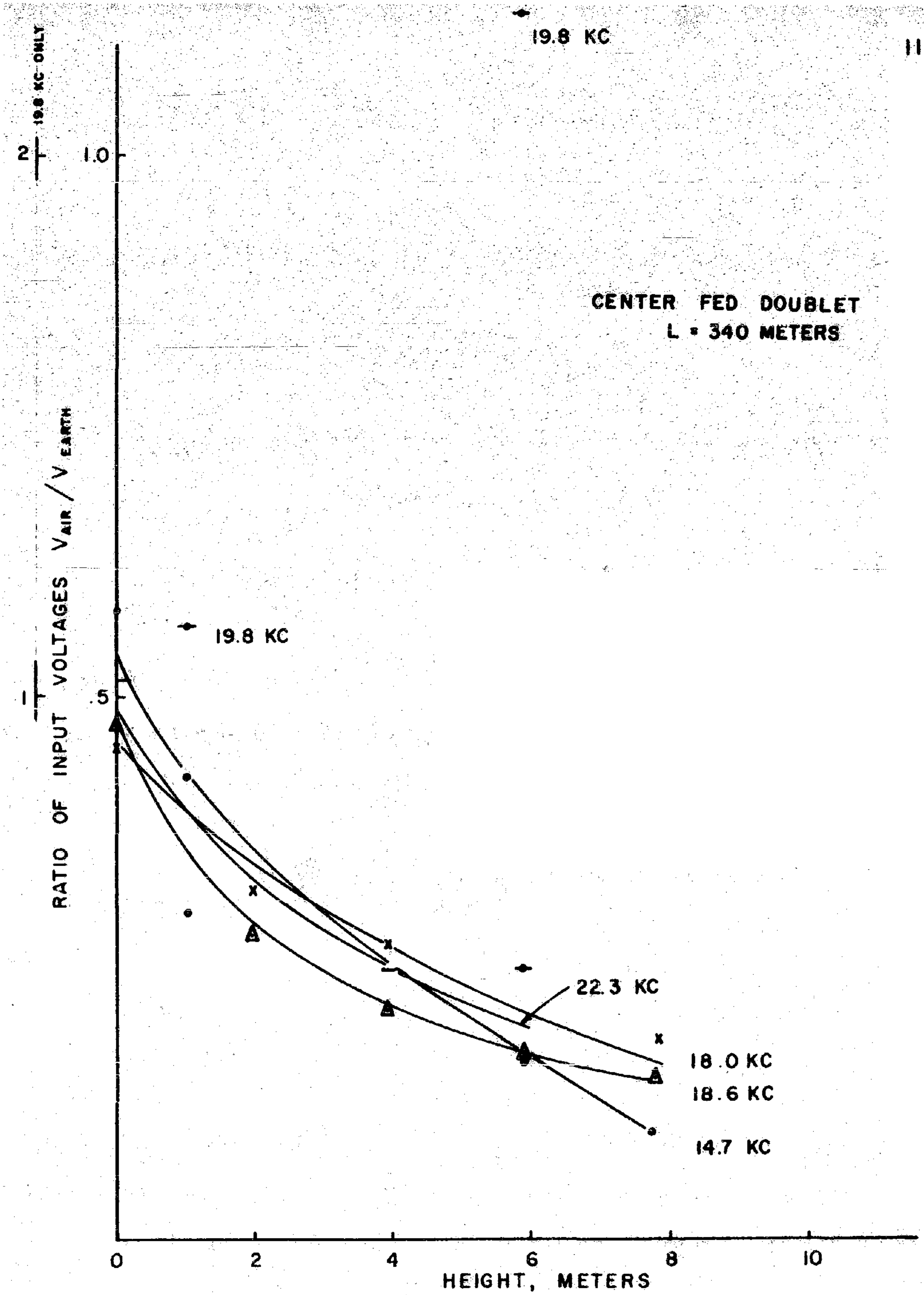
B. Dipole

The procedure described under A was repeated but with the dipole antenna used instead of the monopole. The results of this test are shown in Figure 4. It may be seen that, unlike for the air antenna, the antenna terminal voltage decreases with increasing height. The only exception was one measurement at 19.8 kc from a station in a direction perpendicular to the line of the antennas.

C. Discussion

The primary height gain variations of the two overhead antennas as compared to the earth probes, appears to be associated with their response to vertically and horizontally polarized waves. A perfectly balanced horizontal dipole should respond only to the horizontal component of an incident electromagnetic wave. A horizontal end fed monopole will, however, respond to both vertical and horizontal electric field components. It is evident from the linear height gain relation of the monopole antenna (Figure 3) that the incident waves had a large vertical component and that the output of the antenna is the integrated electric field from the ground to the antenna height.

The height gain relation of the horizontal dipole is somewhat more involved. It is reasonable to expect that in the absence of the antenna, and at the frequencies in question, the horizontal component of the electric



RATIO AIR ANTENNA SIGNAL TO EARTH PROBE SIGNAL

FIG. 4.

field would be uniform from the ground upward over a distance of 8 meters. The presence of the conducting antenna perturbs the electric field in such a manner as to reduce its value along the length of the antenna. However the presence of the antenna has little effect on the intensity of the electric field in the conducting earth. Therefore, the proximity of the conductive earth produces a voltage difference between the ends of the dipole as a result of the capacitive coupling of these ends to the earth below. The capacitance between a horizontal wire and a ground plane varies in an inverse manner with height and is suggestive of the height gain performance of the horizontal dipole antenna.

Table 1

VLF Transmitting Stations

Frequency kcps	Identification	Location	Approximate Distance from Antenna km.	Approximate Direction from Antenna
14.7	NAA	Cutler, Maine	3000	NE
18.0	NBA	Summit, C. Z.	3000	SE
18.6	NPG	Jim Creek, Wash.	2950	NW
19.8	NPM	Hawaii	7300	WSW
22.3	NSS	Annapolis, Md.	2100	NE

VI. SIGNAL-TO-NOISE RATIOS

Signal-to-noise ratios were measured at intervals during several of the height runs using the radio station transmissions as sources. The signal-to-noise ratios were obtained for unmodulated signals. The signal-to-noise ratio for the locked-key transmission is shown in Table 2. For nearly all of the various samples taken and shown in the table, the signal-to-noise ratio was higher for the ground probe antenna than for the overhead antenna.

The signal-to-noise ratios are dependent, of course, on the direction of arrival of the signal being measured. Since the predominant tangential electric field is that associated with the tilt of the vertically polarized field, the earth probe antennas have maximum response for a wave traveling along the line between the probes. The dipole antenna responding to the horizontal component of the field will also have maximum response to a wave traveling in the direction of the antenna wires, but its response to the vertical component due to unbalance of the two halves will be omnidirectional. The monopole will also be omnidirectional in its response to the vertical component of the field.

This effect is noticed in a comparison of the signal-to-noise ratio of the 19.8 kcps station to the other stations. The location of this station was in a direction perpendicular to the antenna line, whereas the other stations were oriented at approximately 45°. Since the earth probe response is

Table 2

Signal-to-Noise Ratios Using C. W. Signals

Connections	Signal-to-Noise Ratio in db			
Frequency in kc/s	14.7	18.6	19.8	22.3
6 meters ht.				
Dipole	--	24	N > S	26
Earth Probes	--	51	N > S	49
1 meter ht.				
Dipole	33	--	--	31
Earth Probes	43	--	--	47
6 meters ht.				
Monopole	42	40	32	43
Earth Probes	44	45	18	44
1 meter ht.				
Monopole	40	37	N > S	40
Earth Probes	47	44	N > S	47

-- indicates no data obtained.

N > S indicates signal-in-noise.

minimized in the direction of the 19.8 kcps station, its signal-to-noise ratio for this station is lower than that of the overhead antenna. With the better orientation of the earth antenna for the other stations, its signal-to-noise ratio is consistently higher than for the overhead wires.

VII. SIGNAL STRENGTH - FREQUENCY SPECTRA

The voltage appearing at the terminals of the earth probe antenna and the voltage at the terminal of one of the overhead antennas were measured simultaneously by the system shown in Figure 1.

The voltages measured were those resulting from natural and man-made sources, and the shapes of the spectra are a function of the sources, the propagation path, local interference, and the response of the antenna. The data obtained is conditioned by all of these factors and the interpretation is not a simple one. Typical results will be presented in this section and discussion of them will be given in the next section. Figure 5 shows the variation of antenna terminal voltage for the earth probe antenna and for the dipole for frequencies from 20 to 50,000 cps. In Figure 6, the ratio of these voltages is given in db.

In Figures 7 and 8, similar curves are presented for the monopole. The dual curves shown for the higher frequencies resulted from sudden changes in the level of activity occurring during the period of observation. These data were taken during daylight hours.

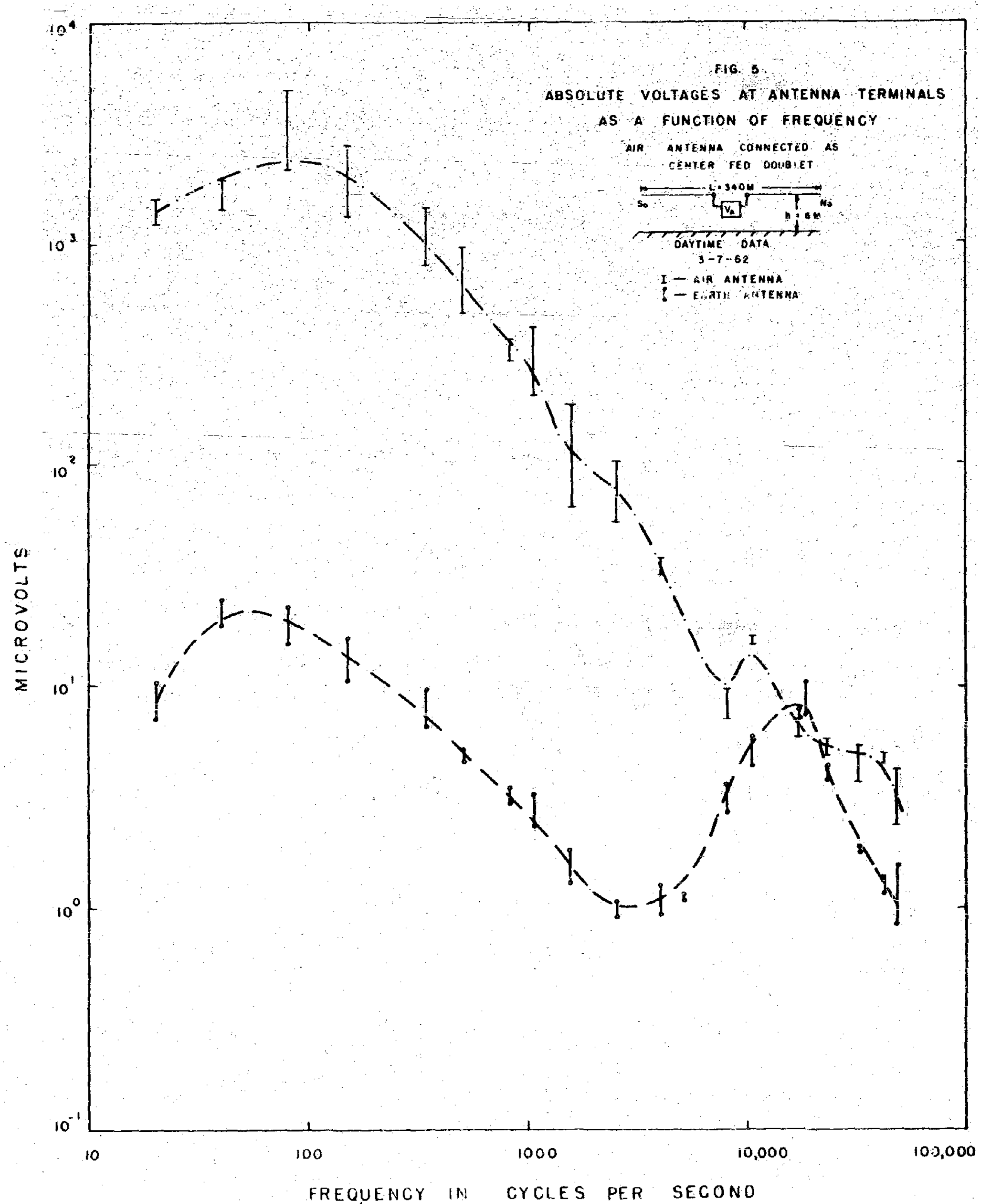


FIG. 5
ABSOLUTE VOLTAGES AT ANTENNA TERMINALS
AS A FUNCTION OF FREQUENCY

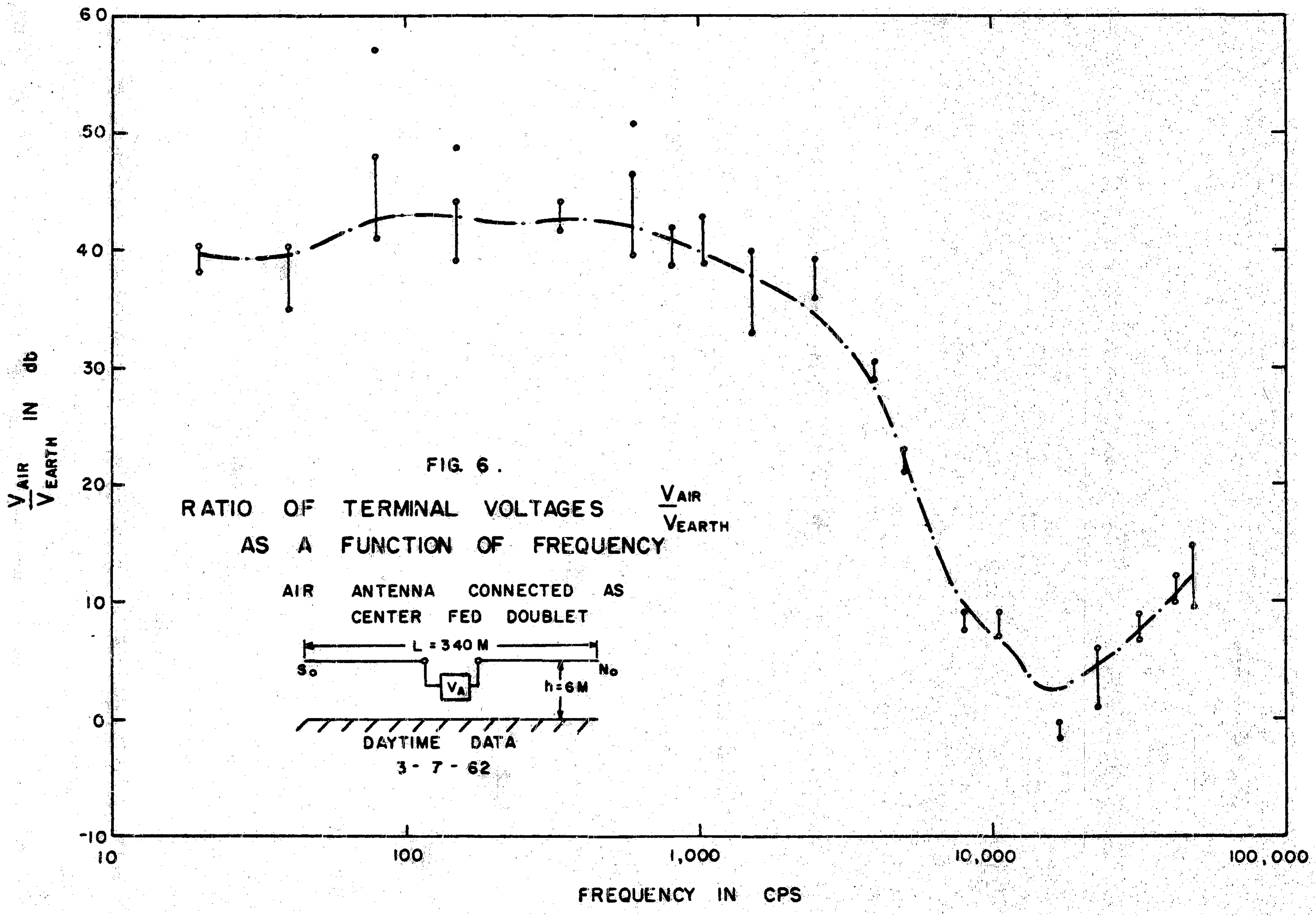


FIG. 6.

RATIO OF TERMINAL VOLTAGES $\frac{V_{AIR}}{V_{EARTH}}$ AS A FUNCTION OF FREQUENCY

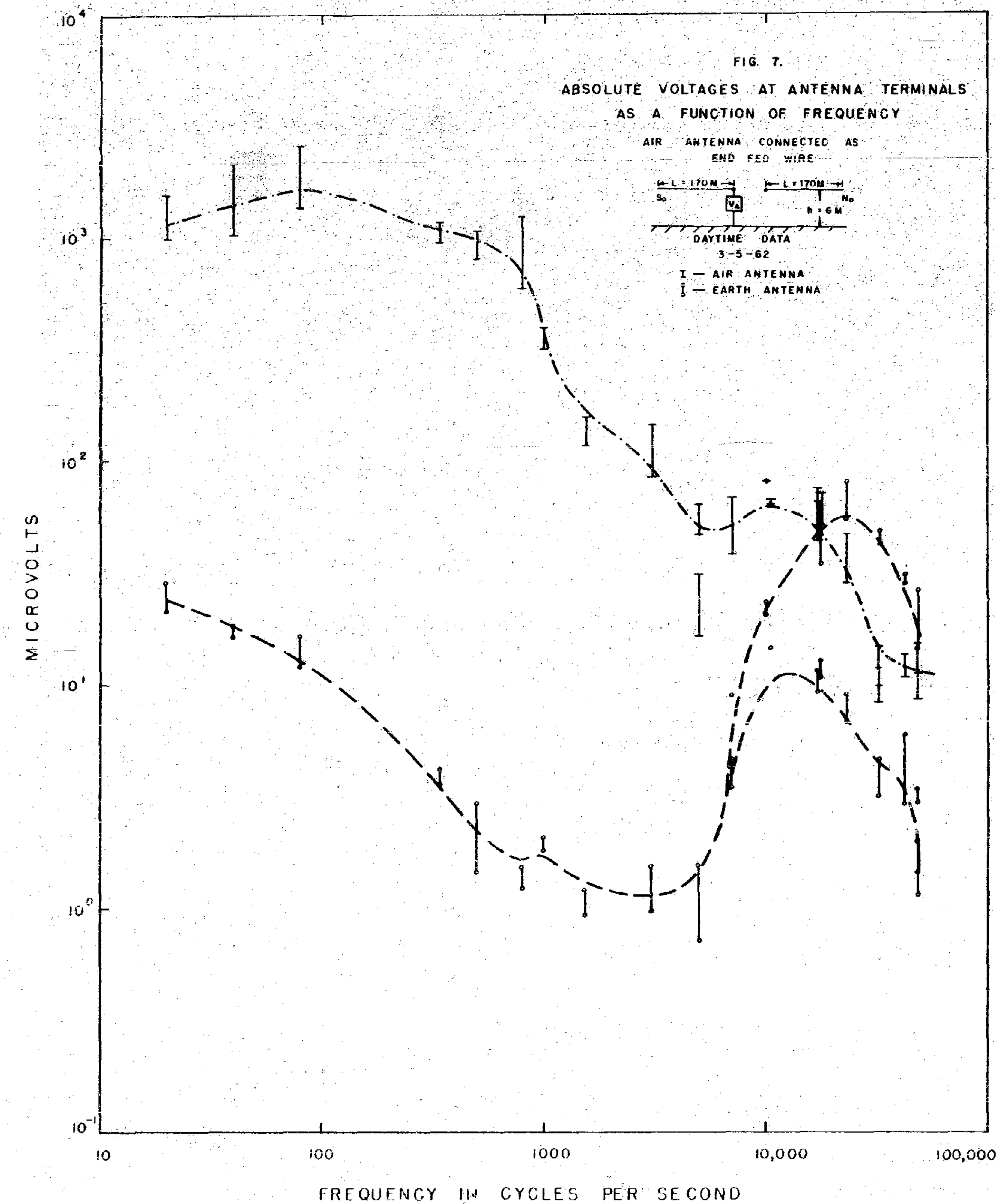


FIG. 7.
ABSOLUTE VOLTAGES AT ANTENNA TERMINALS AS A FUNCTION OF FREQUENCY

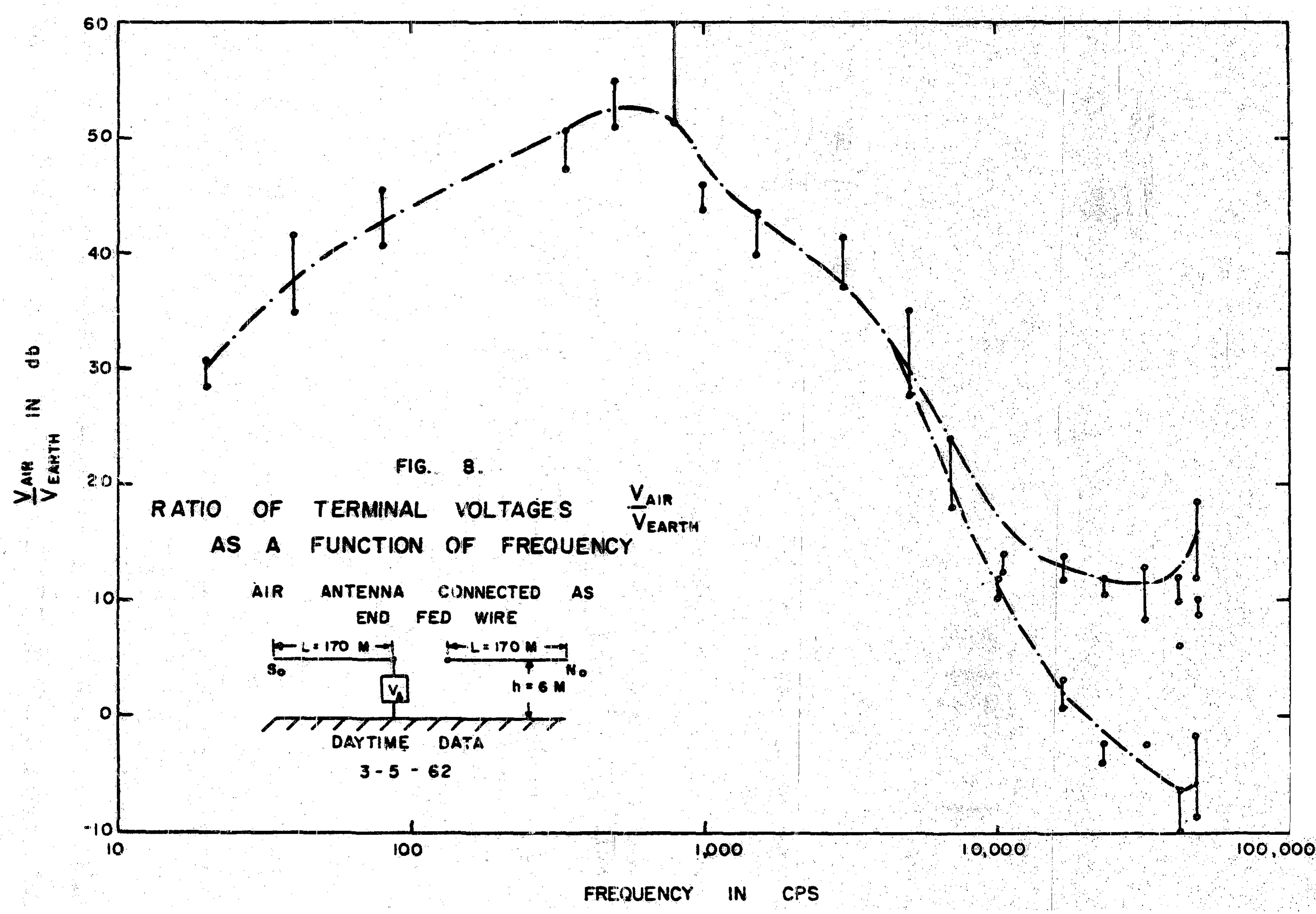


FIG. 8.

RATIO OF TERMINAL VOLTAGES $\frac{V_{AIR}}{V_{EARTH}}$ AS A FUNCTION OF FREQUENCY

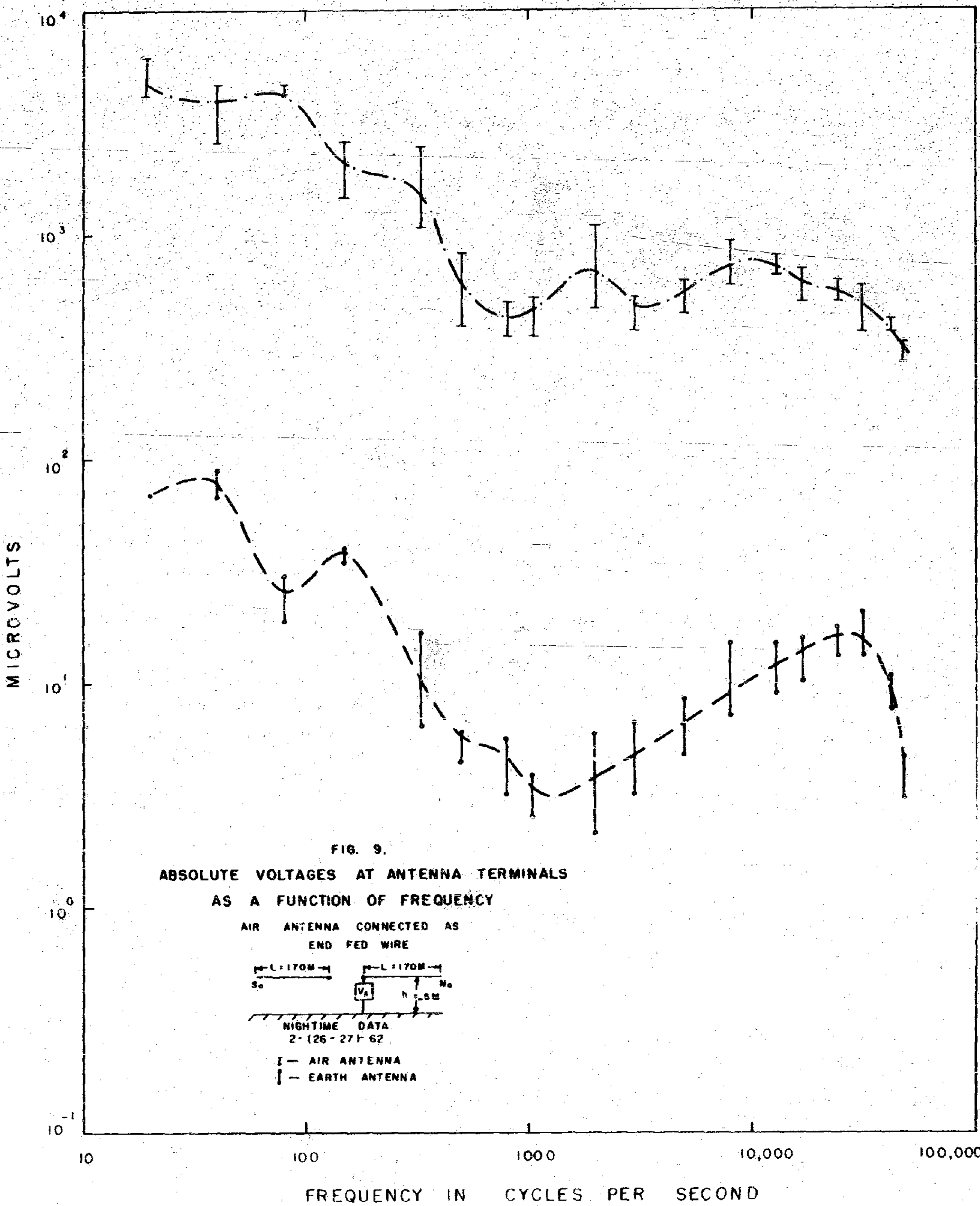
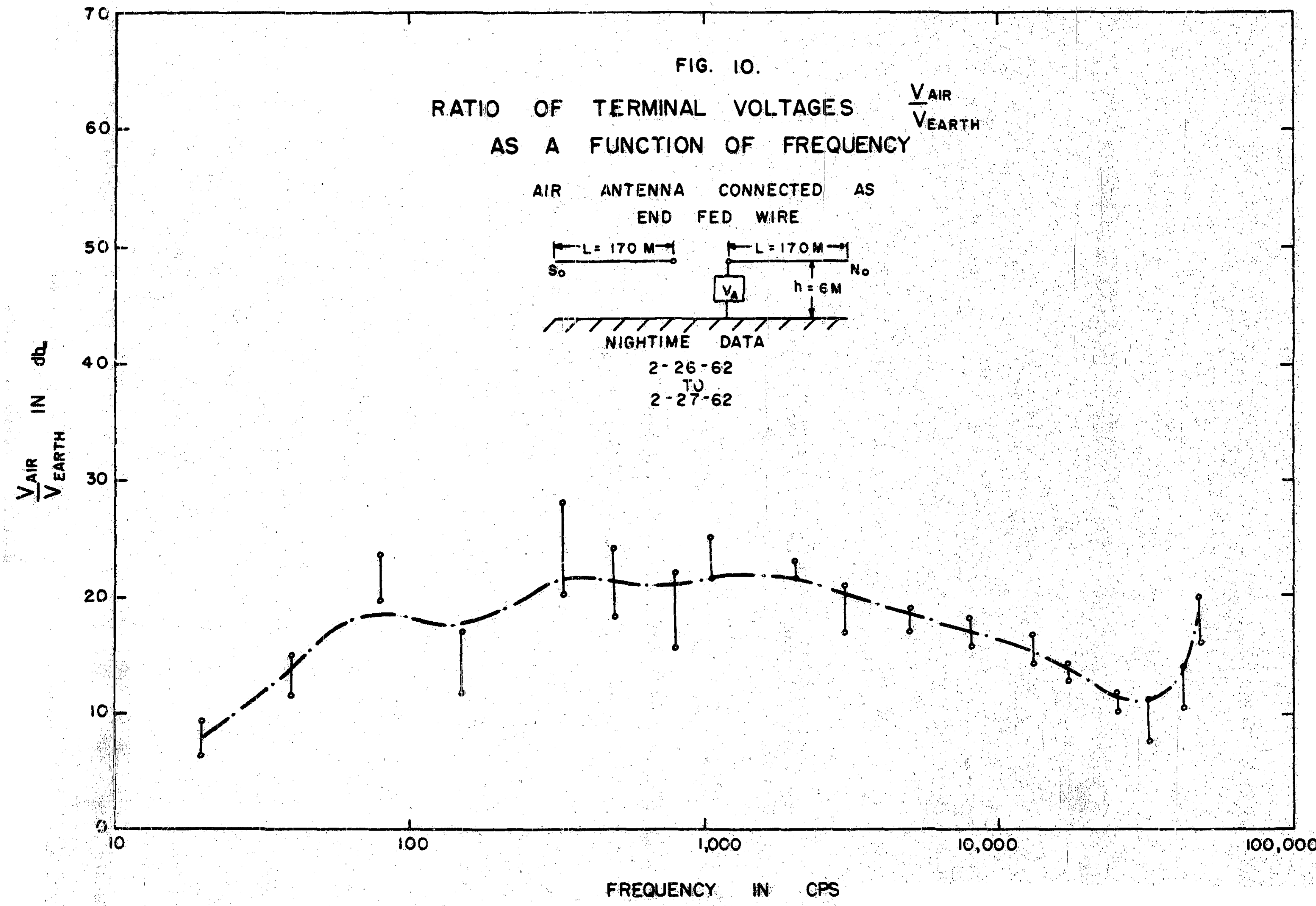


FIG. 9.

ABSOLUTE VOLTAGES AT ANTENNA TERMINALS AS A FUNCTION OF FREQUENCY

FIG. 10.

RATIO OF TERMINAL VOLTAGES $\frac{V_{AIR}}{V_{EARTH}}$ AS A FUNCTION OF FREQUENCY



VIII. DISCUSSION

In VLF transmission over a reasonably good conductive earth, the predominant polarization of the electric field will be normal to the earth. Due to the finite conductivity of the earth, a small component of horizontally polarized electric field will exist. This component will be in the direction of propagation of the wave. The monopole antenna will respond to the vertical component of the electric field and the dipole and earth probe antennas will respond to the horizontal component. The indicated output of the monopole will be the integrated electric field from the ground to the antenna height. The indicated output of the dipole, if balanced, will be the integrated horizontal field along the dipole.

In the curves shown in Figures 5 through 10, no account was made for the difference in impedance between the earth and air antenna systems. This was not deemed necessary since in all cases sufficient voltage was available at the antenna terminals to completely overide the system noise. Quoted signal-to-noise ratios are made only for the cases of coherent signals in the presence of incoherent noises originating external to the measuring apparatus and the antennas.

Although Figures 5, 7, and 9 show that the output voltage of the overhead systems is consistently higher than that of the earth probes under most conditions, the voltage output of the antenna system should not be regarded as the sole criterion for evaluating the system. The signal-to-noise ratio would appear to be a very important factor in this evaluation.

The higher signal to noise ratio of the earth probe output would appear to be due to the fact that the transmission modes for the noise are different from those of the station signals.

IX. CONCLUSION

In view of the higher signal-to-noise ratios obtained with the earth probe antenna as compared to the overhead antenna, it is concluded that this system is superior for many application to the overhead system.

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